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UCRL-JC-153261

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**August 21, 2003**

2003 Third International Conference on Inertial Fusion  
Sciences and Applications, Monterey, CA  
September 7-12, 2003

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This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

## ENABLING TECHNOLOGY FOR FABRICATION OF METER-SCALE GRATINGS FOR HIGH-ENERGY PETAWATT LASERS

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*We report on the construction, commissioning and characterization of a reactive ion mill capable of submicron pattern transfer into hard dielectric materials on optical substrates as large as 2 x 1 m, for application to fielding high-Energy Petawatt (HEPW) capability on the National Ignition Facility (NIF) laser. Scanning Faraday cup current probe measurements have been used to optimize the ion beam spatial uniformity. Using process parameters obtained from this study, an 81 cm round optic was etched, and etch depth uniformity of +/- 3.1% absolute was demonstrated. Uniformity of multilayer dielectric gratings of designs employing an etch-stop layer will have etch depth uniformities of approximately a factor of 10 better than this. We also report on initial results of etching multilayer dielectric gratings.*

### Introduction

Due to their higher peak and average power handling capability, multilayer dielectric (MLD) gratings<sup>1-3</sup> represent the state of the future for high-power short-pulse lasers based on chirped-pulse-amplification<sup>4</sup>. Past and present Petawatt class lasers, based on LLNL's original Nova Petawatt<sup>5</sup>, use 94 cm diameter gold-overcoated holographic master gratings, which are fundamentally limited to ~400 mJ/cm<sup>2</sup> for pulse durations on the order of a picosecond. In 2000, LLNL fabricated an MLD grating 355 x 150 mm in aperture that exhibited >99% diffraction efficiency for 1030 nm light at 63° incidence angle, that was used for a high-average power 50W short pulse machining laser<sup>6</sup>. In 2002, Jobin-Yvon-Horiba delivered high-peak power MLD gratings at 420x210 cm aperture to France's LULI laser<sup>7</sup>. Plans for short pulse capability on the NIF laser, among others, require either gratings of

significantly larger aperture, or precision phasing of multiple gratings by a tiling approach<sup>8</sup>. LLNL's grating manufacturing capability includes meter-scale holographic exposure and wet-processing tooling, but our ability to etch high-aspect ratio grating structures into hard dielectrics has been limited in the past. The recent commercial development of linear RF powered ion sources for large area processing has opened up the possibility of etching processes based on linear tooling, a fundamental departure from the radially symmetric filament-based ion sources and planetary substrate motion of past devices. Such tools have the potential to provide uniform etching over large areas in compact geometries.

### Etcher construction

We procured a prototype linear ion source from Veeco Ion Tech Inc., and built a custom-etching tool around it. This source is powered by 13.56 MHz RF at 2kW and produces a collimated ion beam 1.1 m long and 6 cm wide. Three stainless steel vacuum chambers from LLNL's mothballed Atomic Vapor Isotope Separation Facility, each 1.8 x 1.5 x 0.6 m (LxHxW) were joined to form one continuous chamber. The ion source was mounted vertically into a modified door of the center chamber, and a linear motion track was mounted along the floor to translate the substrate back and forth across the beam. A conceptual drawing is shown in Figure 1, and a photograph of the installed tool is shown in Figure 2. The chamber is capable of  $8 \times 10^{-7}$  mmHg vacuum during pumpdown, and is plumbed for three gases, argon, oxygen and a Freon compound for fluorine-based reactive chemistry for enhanced etching selectivity of oxide to mask material.

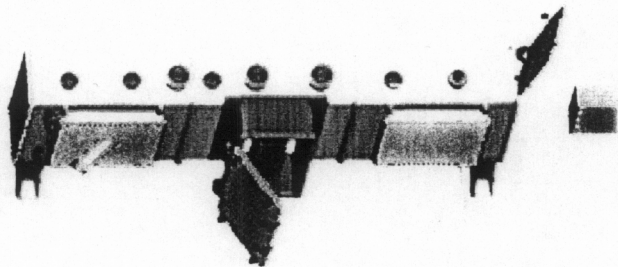


Figure 1. Schematic of ion-beam etching tool, showing ion source inserted in center door, and substrate loaded into end door at right.

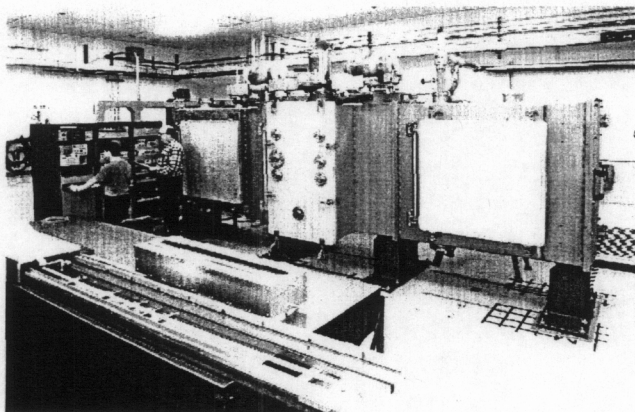


Figure 2. Photograph of the ion-beam etcher. Ion source and substrate linear motion track in foreground awaiting installation.

### Etcher Characterization

The uniformity of the etched pattern is related to the uniformity of the ion beam, which provides reactive gases and energetic ions that impinge upon the substrate and remove material. The beam uniformity over the length of the source varies mainly because of non-uniformity in the RF power emission. This can be improved by optimal distribution of the gas flow rates over the length of the source, adjustment of the total system pressure, and by

placement of partial grounding plates to attenuate the RF power locally along the length of the source.

We built a Faraday cup current probe consisting of a stainless steel housing with a slotted aperture 20 cm wide by 0.75 cm high to allow the ion beam to impinge upon the carbon electrode mounted inside. This electrode is electrically isolated from the grounded housing and connected electrically to the beam control module, which applies a bias voltage and displays the current measured. All materials in the probe assembly are vacuum compatible and bake-able. The probe is mounted on a computer-controlled stage that provides vertical motion to scan the probe in the ion beam. The stage and probe are in turn mounted onto the substrate transport system, which allows positioning the probe laterally. A high-resolution scan of the ion beam current as a function of horizontal position across the nominal 6 cm width of the ion source is shown in Figure 3.

A number of experiments were performed varying the gas pressure and distribution, RF attenuator position, and acceleration and beam voltages, with the figure of merit being the RMS uniformity vertically over an 80-cm beam height. The ion current uniformity as a function of the beam height for the empirically-determined optimum parameter set is shown in Figure 4.

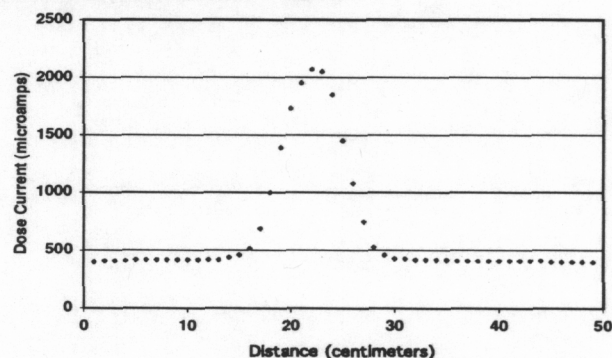


Figure 3: Probe current as function of horizontal position for Faraday Cup probe mounted vertically and scanned horizontally across the center of the ion source. This shows the beam width to be approximately 10 cm at a source to substrate distance of 31 cm.

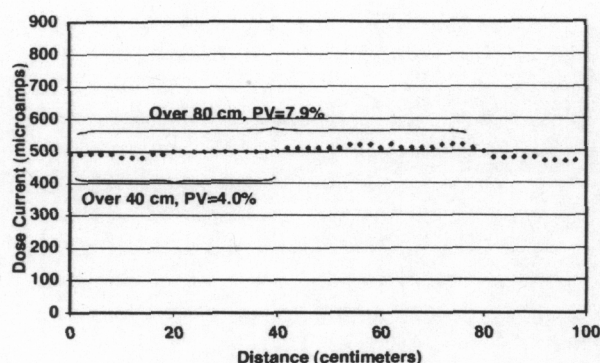


Figure 4: Ion current as function of vertical beam position for optimal conditions.

### Etching Experiments

An 81-cm round window glass substrate was coated on site with approximately 300 nm of Ta<sub>2</sub>O<sub>5</sub> and etched according to the above recipe, as a test of uniformity at large scale. Window glass was used to reduce costs, and Ta<sub>2</sub>O<sub>5</sub> was chosen because it etches with the same chemistry as SiO<sub>2</sub> and the high index contrast between it and the window glass allows for inexpensive and fast interferometric measurements of the film thickness. The substrate mounted in the etching chamber is shown in Figure 5. The thickness of the Ta<sub>2</sub>O<sub>5</sub> layer was measured at 2.5 cm intervals along the x and y axes of the substrate at its midpoint, before and after the etch run. The run was planned to remove approximately half the deposited film. The difference in the film thickness, representing the amount of etched material, is plotted in Figure 6. Horizontal etch depth uniformity is less than 3% absolute over 80 cm. The vertical nonuniformity of ~6% absolute agrees well with the vertical distribution of the ion current plotted in Figure 3. According to existing HEPW grating designs, a 6% variation in etch depth will not affect diffraction efficiency. However, since we do a slight overetch and employ an etch-stop layer with a selectivity of >10:1, the variation in etched depth with this tool at these conditions on a real grating would not be measurable.

Initial etching experiments on witness multilayer dielectric gratings have begun. Figure 7 shows a scanning electron micrograph of a 1740 line/mm MLD grating etched into a 700 nm thick SiO<sub>2</sub> top layer. Based on current removal rates, a grating 80 cm in long aperture could be transfer-etched to completion in approximately 9 hours under these conditions. Experiments to determine the effect of ion beam focus on the shape of the etched profiles are ongoing.

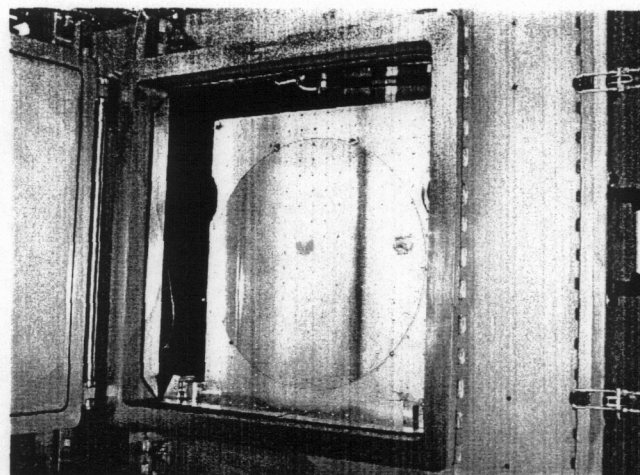


Figure 5. 81 cm round Ta<sub>2</sub>O<sub>5</sub>-coated optic mounted in etching chamber.

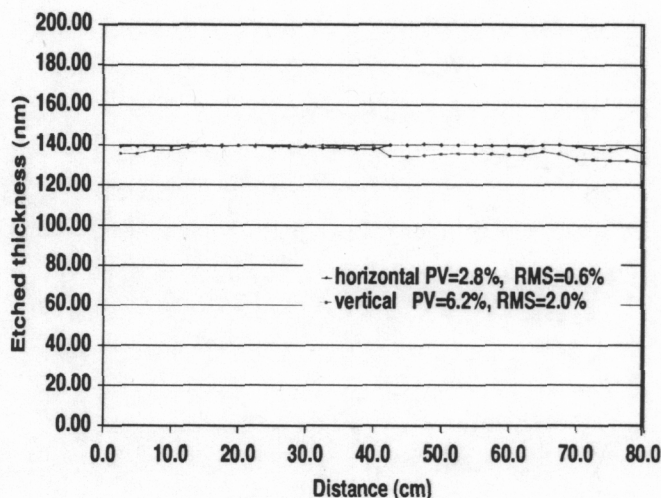


Figure 6. Ta<sub>2</sub>O<sub>5</sub> film thickness removed on vertical and horizontal lineouts over 81 cm round optic.

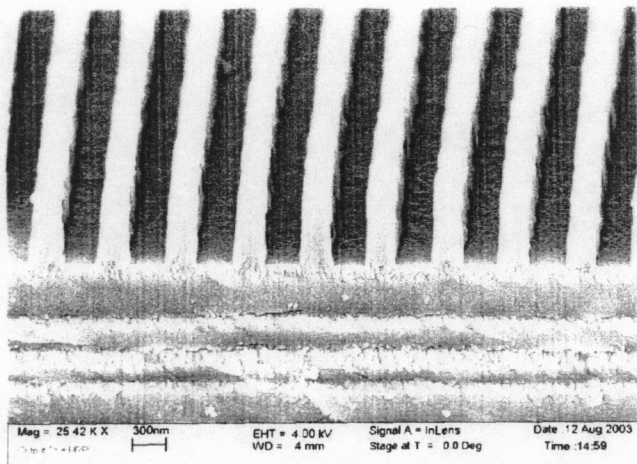


Figure 7. Scanning electron micrograph of 1740 line/mm witness multilayer dielectric grating etched in the large ion-beam etcher.

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